Environmental Forecasting, Assessment, and Decision Making for River Basin Management

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Abstract

The U.S. Army Corps of Engineers is developing a system of tools to improve environmental forecasting and decision-making in comprehensive water resources management. Currently available tools include geospatial assessment techniques, habitat models, single- and multi-dimensional numerical models, and ecological models based on concepts of bioenergetics, individual-based response, and trophic structure. Applications of these models for sustainable water resource management provide opportunities to forecast the effects of landscape changes, owing to activities such as urbanization, ecosystem restoration, water resource project operations, etc. at various temporal and spatial scales. Since resources (e.g., data, time, expertise, funding, etc.) are often limited, a tiered or hierarchical approach to water resources forecasting is recommended. For example, geospatial technologies can be used to develop land cover and land use data layers for applications in habitat based models or numerical models for watershed runoff predictions. Another level of applications combines predictions of land use changes and subsequent changes in material loadings with biological responses in aquatic systems using multi-dimensional models. This suite of tools is being developed within a framework to "customize" comprehensive tool selection in the decision-making process, thus allowing user communities to maintain databases, conduct alternative analyses, and transfer information in a user-friendly format. A rationale for the approach and example applications are presented.

Keywords: watershed assessment techniques, geospatial, numerical models, model integration, river basin management, decision support.

1 Introduction

Sustainable river basin management requires capabilities to predict effects of land use changes and water resource management activities on receiving waters. These capabilities typically exist as a variety of individual tools that vary in levels of complexity. The tools are mostly used in separate analysis with output results from one tool often used as input data to another. This approach is often used for small-scale studies. Larger-scale studies (such as in major river basins) often require a "suite" of tools that can be efficiently "linked" for a systemic application. Since no single tool can be applied for all watershed analyses, a suite of tools, delivered via a framework using common data formats is being developed.

This framework of tools should provide capabilities to 1) compile and format watershed and river basin data, 2) input the data into forecasting tools, 3) facilitate scenario analyses, 4) graphically display results, and 5) provide user friendly access to stakeholders and decision-makers. Types of watershed and river basin data include land use, topography, hydrology, flow, river channel morphometry, and water resource management activities such as reservoir operations. Tools used to compile and format data consist of data retrieval tools for national databases (e.g., U.S. Geological Survey flow data, U.S. Environmental Protection Agency water quality data). Capabilities for scenario analyses include techniques for easily changing land use covers (e.g., urbanization trends) and water management activities such as changes in reservoir operations. Graphic displays such as maps and graphs depicting relative changes associated with each scenario analysis can then be used to effectively communicate potential management consequences to stakeholders and decision-makers.

River basin management is complex and various paradigms exist that can be used in management decisions. Many of these paradigms focus on flow conditions and ecological integrity of the river and its floodplain [1, 2, 3, 4]. Ward et al. [5] provide a broad synthesis of riverine landscape diversity that includes concepts of landscape dynamics within river corridors, fluvial processes, hydrological connectivity, biotic connectivity (terrestrial and aquatic), and species diversity as a function of interactions between disturbance and productivity. Social implications, such as a desire for selected species as illustrated in a case study of adaptive management for the Grand Canyon [6] and human needs [7] must also be considered as management decisions are made.

2 Watershed and river basin tools in decision support

Typically, watershed assessments for forecasting purposes include some level of inventory and data compilation followed by analysis and interpretation. For comprehensive river basin analysis, a suite of tools that forecast effects of watershed inputs to rivers and reservoirs can be used, fig. 1. Watershed models are often used to quantify material export using a variety of assessment techniques (e.g., geospatial distributions of soil types and runoff coefficients or numerical predictions based on a variety of techniques). Riverine and reservoir models are often built on a variety of hydrodynamic codes that essentially distribute and transport the estimated watershed load typically using 1-, 2-, and 3-dimensions. Simulation of chemical processes is also possible. The output from these models (e.g., flow, depth, temperature, suspended sediment, and dissolved oxygen) is then used to provide input to ecological models.

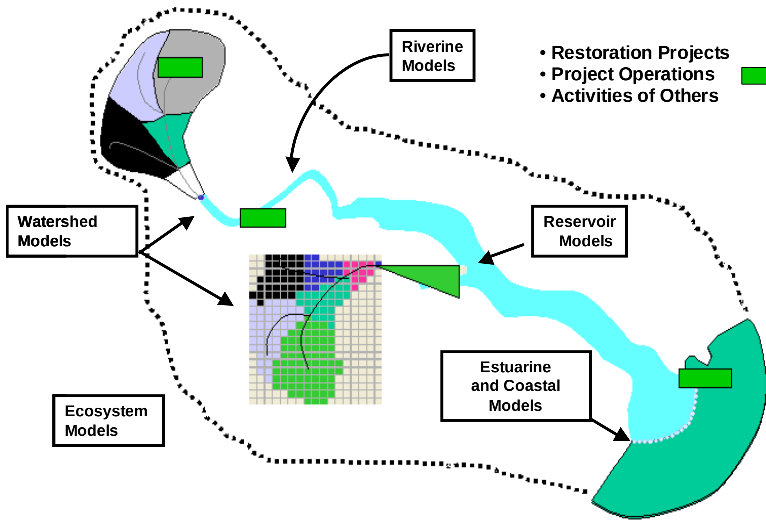

Figure 1: Schematic representation of tools developed for specific regions in river basins.

Using this approach, modelling tools can be selected from a suite based on available resources (e.g., data, time, expertise), thus facilitating a tiered approach to analysis, fig. 2. For example, geospatial data describing current or projected landuses, can be used, in conjunction with topographic data to provide runoff estimates for various land use types. If more detailed information is available, numerical models (with material export either lumped by land use or distributed based on established physicochemical processes into grids) can be used. These data then become inputs for river response modeling that again can employ tools of varied complexity (e.g., geospatial representations or complex numerical models). As complexity in river response increases, 2 and 3-dimensional models may be needed to describe hydrodynamic conditions and material fate and transport. Ultimately abiotic conditions described must be used for forecasting ecological response. This requires knowledge of biotic response to changing conditions.

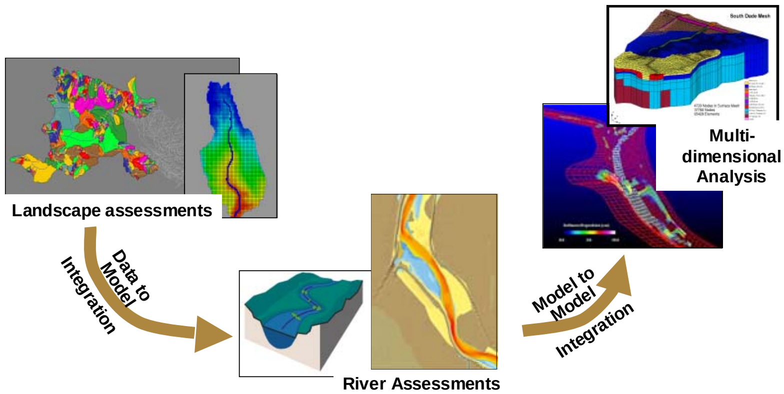

Figure 2: Representation of tiered approach for tool applications.

Building the framework for maximum flexibility and user-friendly applications for scenario analyses requires utilization of common data formats, reusable data storage and retrieval tools, and effectively coupled or interfaced models and databases, fig. 3. The common framework facilitates an iterative process in scenario analysis that allows various levels of data integration, alternative input conditions, and varied model selection resulting in numerous predicted outcomes for the decision-makers to consider. One of the keys to using this approach is to have concurrence among stakeholders and decision-makers regarding the tools to be used in the alternative analysis. This approach also allows the development of response trajectories for use in adaptive management.

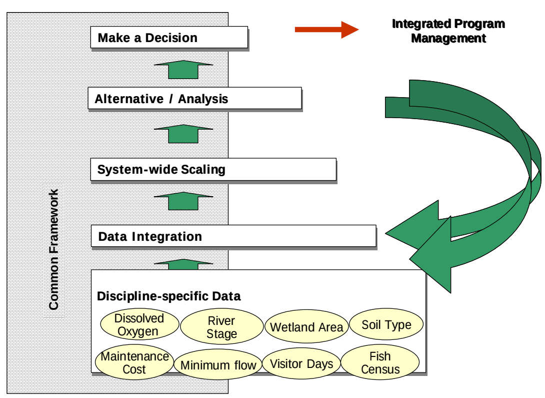

Figure 3: Schematic of a common framework for decision-making.

3 Case studies

Three studies of differing complexities are presented to illustrate the use of a common framework of analytical tools for application in river basin management. The first example provides a demonstration of stakeholder collaboration and consensus building through empirical data analysis for the Savannah River. In the second example, an assessment of the Minnesota River Basin is described with study emphasis on implementation of watershed management techniques primarily for water quality and recreation benefits. The third example illustrates increased complexity with issues of spatial scale and increased diversity of resource user needs in the Upper Mississippi River System.

3.1 Savannah River case study

Numerous hydropower dams exist in the upper and middle Savannah River with major projects in the middle river providing hydropower on demand (e.g., water is released only when required). Typical discharge patterns include high flow releases in the morning and afternoons, primarily on weekdays. Releases on weekends often do not occur. The net result is a widely fluctuating hydrograph in the riverine reaches with marked changes in velocity and stage height on a frequent basis. The lower region of the Savannah River does not have any dams, but the biological community is reflective of the hydrology provided by upstream water management activities.

Stakeholders desire some changes in water management operations that are more conducive to aquatic and floodplain habitats in the lower Savannah River. Using a desire to increase biodiversity as the restoration goal, stakeholders used a science panel to describe flow scenarios that were optimal for representative species in the river and floodplain. Consideration was given to native flora and fauna for the region that likely occurred under a more natural hydrograph. Historic flow records were evaluated to determine representative hydrographs under conditions of dry, wet, and normal years. Peak flow events, considered by the science panel to be critical to downstream habitat development, sustainability, and diversity were identified for each period. Consideration was also given to existing user needs (e.g., hydropower and flood control for floodplain settlements). Operation opportunities (i.e., changing reservoir operation guidelines) were then evaluated to assess the impact on water management needs of a more natural release regime with some strategic peak discharges. The net result was an agreement that representative peak flows will be provided (dependent upon water availability) to simulate biologically important hydrograph features that reflect not only seasonal (e.g., spring high flow) but annual variability (e.g., wet, dry, normal) facilitating biodiversity in both the aquatic and floodplain communities.

3.2 Minnesota River Basin case study

The Minnesota River Basin exhibits a highly agricultural watershed that is experiencing an increased urbanization. The Minnesota River has been impacted by agricultural runoff and changed hydrology associated with flood control and water resource management activities. The stakeholders would like a method of alternative analysis so that decisions on where to allocate resources for watershed improvements will be the most effective. Considerations include primarily location, type, and number of best management practices for agricultural activities associated with row crops and dairy farms and impacts of anticipated increases in urban populations in the basin.

Environmental drivers center around impacts associated with tile drains used in row crop production, an increased demand for water, and increased pollutant discharge associated with urbanization. The tile drains have resulted in a shift to a more surface/subsurface hydrology and major change in runoff patterns. Increased urbanization will also result in a change in runoff patterns (e.g., less retention/infiltration, increased peak and decreased duration in the hydrograph). The Minnesota River currently has sediment and nutrient concentrations that exceed standards and changes in flow have resulted in a decrease in suitable aquatic habitat. The net result is a system with degraded habitat and shift in resource uses. Stakeholders desire better balance for multiple resource uses.

A viable approach for the decision makers is to develop a suite of watershed and riverine assessment tools that includes: geospatial tools for depicting land use; a land use evolution model that allows forecasting of land use change; a watershed model that accounts for surface and subsurface drainage and material transport; and ecological models for forecasting biological response to changes in material loading and flood control operations.

3.3 Upper Mississippi River case study

The natural hydrology of the Upper Mississippi River is considerably altered with numerous navigation and flood control structures (i.e., locks and dams), fig. 4, which has also altered aquatic and floodplain habitat. The entire Mississippi River faces water quality challenges similar to those described above for the Minnesota River with effects manifested in the Gulf of Mexico as summer hypoxia. In addition to sediment and nutrient management activities in the watershed, stakeholders desire a balance between expanded navigation and habitat improvement. Numerous studies have been conducted to evaluate the effects of maintaining a navigation channel (e.g., dredging, flow alterations) on aquatic and floodplain habitat.

Stakeholders and decision-makers have agreed that extensive habitat restoration is in order and several activities are currently underway. However, some uncertainty exists around project implementation related to how many, what type, where, and when. Since a finite amount of funding is available, stakeholders and decision makers desire to develop the most effective implementation and restoration plan that is possible. Another consideration is that the efficacy of several restoration methods and cumulative effects (over both space and time) are relatively unknown.

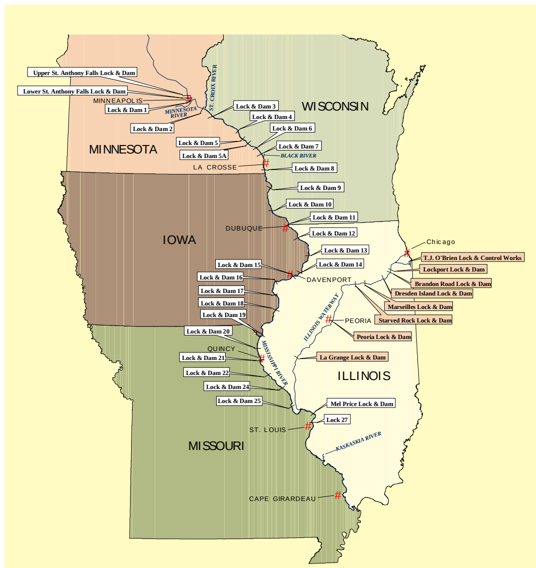

Figure 4: Schematic of the Upper Mississippi River depicting the numerous locks and dams.

The approach is to use geospatial displays of potential habitat restoration projects and hydrodynamic and water quality models coupled to ecological response models (based on trophic structure) to evaluate flood control and navigation management alternatives and forecast ecological response at the individual restoration project level as well as for the entire system. Since implementation of the restoration efforts is taking place over multiple years and biological response is related to project maturity, exact performance and outcomes cannot be accurately predicted. The solution is to have an efficient monitoring program with identified performance metrics so that an adaptive management approach can be used throughout the duration of the restoration to insure a success rate as high as possible.

4 Summary and Conclusions

Sustainable river basin management requires assessment and forecasting technologies that account for effects of major forces. Land use in the watershed impacts river condition by affecting the timing, magnitude, and duration of the water and material loading. Anthropogenic uses (e.g., flood control, navigation, and hydropower) also impact the natural hydrology of rivers. Numerous examples exist of highly altered rivers, their attendant watersheds, and changes in river function and biotic community. To achieve goals of multi-purpose river management, which are often in conflict, a suite of tools maintained in a customized framework will facilitate alternative analysis and decision-making. Many methods are available to assist in the decision-making process. Often insufficient data, expertise, or time exists for optimal tool selection. Providing a suite of tools that can be used in a tiered approach facilitates decision-making for river basin management. Knowing that uncertainty exists throughout the process, forecasting outputs and monitoring of performance metrics is necessary so that adaptive management techniques can be used to increase the chances of successful and acceptable river management.

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